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The Interplay Among Language, Science Knowledge, and Cognitive Strategy Use with Linguistically Diverse Students

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The goal of scientific literacy for all students, including those learning English as a new language, has been established as a national priority. This study examined the patterns of interplay among language production, science knowledge, and cognitive strategy use with linguistically diverse students while performing science tasks. The study involved three groups of elementary students and teachers who shared the same languages, including bilingual Spanish, bilingual Haitian Creole, and monolingual English Caucasian. Three science tasks were used: weather phenomena (tornadoes), simple machines (levers), and buoyancy (sinking and floating). The results indicated unique patterns within each language group, but distinct differences among the three groups. The results also pointed to the existence of curvilinear relationships among language, science knowledge, and cognitive strategy use across the three language groups. Implications for enabling students to develop English proficiency and science performance are discussed.

The necessity for scientific literacy has been established as a national priority in the Goals 2000: Educate America Act. Science education reform since late 1980s has stressed "science for all," including those who have traditionally been under-represented learners. National documents on science education standards have been prepared to lay out the course to achieve the goal of equity as well as excellence (American Association for the Advancement of Science [AAAS], 1989, 1993; National Research Council [NRC], 1996). Congress has also affirmed that students in the process of learning English should receive an education equal to that of their English proficient counterparts (Bilingual Education Act of 1994, PL 103-382). The imperative is clear that educators should promote English language proficiency and academic achievement so that all students become scientifically literate. What is missing, however, is an understanding of the process by which language development and academic learning are assessed, promoted, and monitored.

In this paper we present findings of a research study to contribute to the knowledge base for science instruction with students learning English as a new language. This research, supported by the National Science Foundation (Fradd and Lee, 1992-94), examined students' language development, science knowledge, and cognitive strategy use while performing science tasks. The study involved three groups of elementary students and teachers who shared the same language and cultural backgrounds, including bilingual Spanish, bilingual Haitian Creole, and monolingual English Caucasian. The purpose of the paper is to describe similarities and differences in the patterns of interplay among language production, science knowledge, and cognitive strategy use within each and across language groups.

Theoretical Framework

Students' performance in science is determined, to a large extent, by three interrelated areas: (a) language development, the ways students formulate and express their ideas in oral and written communication, (b) science knowledge, the understanding and application of science concepts, science process skills, and science vocabulary, and (c) cognitive strategies, the mental manipulations used in attending to, recalling, and applying information and performing tasks. Each of these areas is briefly described next.

Language forms the basis for thinking. It also serves to structure the ways that ideas are developed, organized, and presented (Newman and Gayton,1964). As students engage in activities, construct explanations, and express their understanding, language is the vehicle of performance and of communicating about the experience (Holliday, Yore, and Alvermann,1994). Variations in communication patterns occur across languages and cultures (Cazden, 1988; Heath, 1983; Villegas, 1991). Some languages view lengthy, repetitive discourse as appropriate, while others view extended length and redundancy as inappropriate or undesirable (Moll, Diaz, Estrada, and Lopez, 1992). Students and teachers from different language backgrounds often have diverse interpretations about how to communicate both verbally and non-verbally. Communication differences also occur as students and teachers make decisions about, for instance, when to talk, how much to say, and how to take turns in group interactions.

Science knowledge refers to the understanding of science content and science process skills in carrying out tasks and constructing meaning (AAAS, 1989, 1993; NRC, 1996). Prior knowledge and personal experience play key roles in acquiring new knowledge and in performing science tasks (Driver, Asoko, Leach, Mortimer, and Scott, 1994; Posner, Strike, Hewson, and Gertzog, 1982). The role of prior knowledge is especially important for students learning English as a new language. The knowledge these students bring from their cultural and linguistic backgrounds may differ from the knowledge of the mainstream teachers and peers (Atwater, 1994; Lee, Fradd, & Sutman, 1995; Rakow & Bermudez, 1993). Their prior exposure to science instruction may also differ from the requirements of the U.S. school settings in which they are expected to perform (Barba, 1993; Matthews and Smith, 1994).

Vocabulary also plays an important role in understanding and communicating science information (Lemke, 1990). Learning specific vocabulary to communicate science concepts is not a simple matter of learning a list of terms. Rather, the process involves understanding relationships among ideas, terms, and meanings. Learning science vocabulary can be more complicated for bilingual students than for students with only one language. Comparable terms and parallel ways of considering ideas may not exist cross-linguistically. Even when comparable terms exist in both languages, they may not be used with the same frequency or in the same manner (Bialystok and Hakuta, 1994). In addition, students for whom English is a new language may understand science terms and concepts but lack an understanding of how to convey information concisely (Michaels and O’Connor, 1990).

Cognitive strategies provide the means for organizing, executing, monitoring, and assessing one’s performance. Research indicates that higher-level strategies (e.g., monitoring of comprehension, elaboration of ideas, connection among ideas, and organization of information) are associated with more active engagement and more complex performance, compared with surface-level processing strategies (e.g., memorization, repetition, guessing, and copying) (Blumenfeld and Meece, 1988; Lee and Anderson, 1993; Nolen and Haladyna, 1990). With a few exceptions (see Chamot, Dale, O'Malley and Spanos, 1992; Knight and Waxman, 1990; Padron, 1992), most studies on cognitive strategies have not taken into account different languages or cultures. Considering that cognitive strategies are products of cultural experiences as well as instruction, the relative frequency and effectiveness of strategy use may differ among diverse groups of students (Lee, Fradd, and Sutman, 1995).

The interplay of language, science knowledge, and cognitive strategy use occurs in the science performance of all students. This interplay is particularly important for bilingual students faced with the multiple requirements in developing scientific literacy. Because these students must develop English language proficiency while acquiring the academic language of science, they are more vulnerable to discontinuities that can occur when any aspect of the learning process fails to develop adequately (Barba, 1994; Chamot and O'Malley, 1994). Research that integrates findings across language groups can provide important insights into the interplay of language, science knowledge, and strategy use for students and teachers in multilingual settings.

The study discussed here examined these key aspects of science performance as related to three groups of elementary students. The study included student dyads of the same language, culture, and gender with teachers from the same backgrounds. This research context provided opportunities to observe culturally and linguistically congruent science performance and to probe students' understandings of science in ways that promoted their participation and performance. The purpose of the research was not to document which language group performed most effectively, but to describe the ways that diverse groups of students and teachers engaged in science tasks and to consider the interplay of language, science knowledge, and cognitive strategy use in the acquistion of science literacy. The findings suggest ways to enhance science learning for linguistically diverse students and to extend the knowledge base needed to make science learning a reality for all students.

Method

Student and Teacher Participants

The study was conducted in two elementary schools in the Southeast with high percentages of culturally and linguistically diverse students. Three groups of fourth-grade students participated in the study: (a) monolingual English students, (b) bilingual Hispanic students, and (c) bilingual Haitian students. The study included 24 students in 12 dyads; four dyads in each of the three groups with equal numbers of male and female students. Six teachers participated representing each of the ethnolinguistic and gender groups of students. All but one teacher had participated in graduate-level training in English to speakers of other languages (ESOL).

Science Tasks

The study used three science tasks: (a) weather phenomena (tornadoes), (b) simple machines (levers), and (c) buoyancy (sinking and floating). Using the elicitation protocols designed to ensure conceptual and procedural consistency, teachers elicited language samples from students, engaged them in science activities and explanations, and probed their use of cognitive strategies. Successful completion of these tasks required that students carefully observe events, make predictions, explain the results, and make generalizations.

For each science task, an elicitation protocol was designed to ensure conceptual and procedural consistency. Tasks were briefly introduced by engaging students in observation and having them describe phenomena at a concrete level (initiating activity). Next followed the students' manipulation of materials and explanations of the phenomena (manipulating activity), expression and communication of observations and explanations related to the activities in written and oral forms (literacy activity), and finally statements of generalizations at a more abstract level (concluding activity). These tasks created opportunities for the students to carefully observe events, describe phenomena, make predictions, explain the results, apply the concepts to real-world situations, and make generalizations.

Data Collection and Analysis

Student dyads and teachers of the same language, culture, and gender participated in science activities. The decision to use dyads, rather than individuals, was predicated to create a setting that could promote social and academic communication and stimulate language production, while minimizing test-like conditions. Data were collected through the use of audio and video tape recordings to observe both verbal and non-verbal interactions. Each dyad spent approximately 30-50 minutes on each science task. A total of 36 task sessions, three sessions with each of the 12 dyads, were recorded. After each task, the teachers transcribed the audio tapes of the elicitation sessions they had conducted. Sessions conducted in Spanish or Haitian Creole were transcribed and then translated into English. Once the audio transcriptions were complete, video recordings were used to observe and analyze non-verbal behaviors.

For each of the science tasks, coding systems to analyze students' language production, science knowledge, and cognitive strategy use were developed. Data analysis involved a range of qualitative methods identifying major themes and patterns, and quantitative methods summarizing frequencies and total scores. Considering that the students in each dyad influenced each other's performance, the dyad, rather than individual students, was the unit of analysis, except for written language samples. Data analyses were conducted by an interdisciplinary team of researchers using procedures to insure triangulation. For each set of data interrated agreement was over 80 percent. After the findings were compiled within each group, themes and patterns among the three groups were examined (Erickson, 1986; Miles and Huberman, 1994; Straus and Corbin, 1990). At the conclusion, the teachers read and verified the accuracy of the results.

Language development. Although language development can be observed in a variety of ways, the analysis focused on three areas of language production: (a) written language samples summarizing science activities at the completion of each task, (b) the length of time used to complete each task, and (c) the length of speaking turns. Coding systems were developed to analyze language production in each of these areas. Written samples were analyzed in terms of length using four-interval ratings: (a) 1-3 lines (rating 1), (b) 4-7 lines (rating 2), (c) 8-15 lines (rating 3) and (d) a full page or more (rating 4). The average time that students used for writing was approximately 15 minutes. In order to obtain length of time measures for completing each task (not including the time spent on writing), the video recorder was programmed to imprint the time in hours, minutes, and seconds. The mean length of turn for each student was determined by counting the number of words per speaking turn.

Science knowledge. Students' knowledge of science was analyzed with regard to two aspects: (a) accuracy of science knowledge, and (b) use of science vocabulary. For each of the three science taks, the level of science knowledge and the list of science vocabulary were determinted based on a review of the science textbooks and district science objectives for intermediate grade levels. The tornado task involved three issues: (a) the nature of tornado in terms of appearance, shape, size, and wind strength, (b) the formation of tornado, and (c) damage and precaution. The lever task considered two aspects of a lever system: (a) the position of the fulcrum, and (b) comparing the lengths of the lever arms (i.e., distances from the fulcrum to the applied force and from the fulcrum to the load). The buoyancy taks involved two issues: (a) sinking a clay ball, floating a boat made of the same clay, and forcing the clay boat sink, and (b) changes in the water level. Three versions of science vocabulary in English, Spanish, and Haition Creole were developed.

Using the coding systems for science knowledge and science vocabulary, student responses were analyzed into mutually exclusive categories. For each of 21 segments in the three science tasks, the level of science knowledge was judged into one of three categories: (a) correct response (2 points), (b) partially correct response (1 point), and (c) incorrect or ambiguous response (0 points). In a similar manner, students' use of science vocabulary was judged into one of three categories: (a) appropriate/accurate use (1 point), (b) inappropriate/inaccurate use (0 points), and (c) no use (0 points). The maximum score for science knowledge was 42 points, and for science vocabulary it was 21.

Cognitive strategy use. Students' use of cognitive strategies was analyzed using a coding system developed from two sources: (a) transcripts and viewing of videotapes of the study, and (b) existing instruments on cognitive strategies in science education (Blumenfeld and Meece, 1988; Meece, Blumenfeld and Hoyle, 1988; Nolen and Haladyna, 1990). While the previous studies focused on students' self-report, this study included both the analysis of strategy use during science task performance and self-repairs at the completion of each task (Lee and Anderson, 1993).

The coding system included the following strategies: using personal experience and prior knowledge, relating daily examples and events, making analogies, comparing and constrasting, questioning and requesting clarification, seeking teacher assistance, recognizing confusion and difficulty, collaborating with peers, using metaknowledge, considering alternative ideas, and using resources and imagination. Using the coding system developed for the study, the frequency of use for the cognitive strategies was obtained. In addition, teachers asked the students, "Tell me about any special techniques or methods that helped you do well today." (or rephrased variations) at the end of each task. The frequency and content of these self-reports were analyzed.

Results

The findings indicate distinct patterns of interplay among language production, science knowledge, and cognitive strategy use within each language group and across the three groups. It should be emphasized that although each dyad displayed common patterns of each language group, there were certainly wide variations among the dyads within each group. The summary of the results is presented in Table 1.

Bilingual Spanish-Speaking Group

Language. These students and teachers produced the longest responses in both oral and written communication among the three groups. They engaged in simultaneous speech. Often when one member of the triad began speaking, others freely took turns following up on ideas and contributing and completing thoughts. Multiple talk through shared turn-taking produced an overlap in the discourse of the group. At times, however, they also gave long, uninterrupted monologues. During both, the group constructed communication and extended monologues, discourse tended to be recursive and redundant.

	Language Production			Science Knowledge		Cognitive Strategy Use
	Length of writing	Length of task time	Length of turn	Knowledge	Vocabulary	
Monolingual English Caucasion	2.3 (0.7)	21.4 (2.0)	14.1 (3.9)	22.2 (5.3)	5.5 (2.6)	14.8 (7.0)
Bilingual Spanish	2.8 (0.5)	27.9 (2.5)	21.2 (6.4)	16.3 (3.6)	4.0 (2.5)	16.8 (7.2)
Bilingual Haitian Creole	1.9 (1.2)	24.0 (2.7)	9.8 (1.4)	8.3 (5.9)	1.3 (0.8)	3.5 (2.3)
Total (12 dyads)	2.3 (0.9)	24.4 (3.6)	15.0 (7.2)	15.6 (8.1)	3.6 (3.0)	11.7 (8.1)

Table 1. Relationships among Three Aspects of Science Performance (M, SD)

Most conversations involved both verbal and non-verbal communication. They often used hand gestures prior to or in conjunction with verbal expression. Sometimes, gestures supported or supplemented the meaning provided through words. For example, when talking about a tornado, all students used their index fingers pointed spiraling upward or downward to express the concept of "swirl."

Science knowledge. Although these students generally demonstrated science process skills, some of these skills, including causal interpretation and generalization, seemed to be still under development. Sometimes students expressed science concepts but lacked the vocabulary and discourse format for conveying precise meanings. As a result, they tended to produce large amounts of language to communicate ideas that could have been expressed in concise statements. In the following example, a dyad of two boys were presented with a set of pictorial illustrations for the lever task. They were asked to arrange the task cards in sequence to describe the event (in this case, while driving in a car on a road, a man was blocked by a big rock, a small rock, and a wooden board on the road) and to explain the concept of lever. One boy gave a reasonable description of the event and the explanation for the use of a lever in elaborate and extended personal discourse without using specific science vocabulary:

> A man was driving on the street and had to stop because of a big rock, a small stone, and a piece of wood. And he stopped there and got out of the car thinking: How can I move it? And he thought about putting the big rock on the edge of the piece of wood and the small one underneath it, and putting the finger on it [at the other end of the wooden board], he was going to move the other part. Then, he could move his car. And once he finished, he left and drove away.

At the conclusion of each task, the teachers asked students about their personal experiences and prior knowledge pertaining to the task. The teachers asked whether students could recognize satellite photos of a hurricane and a tornado (task one),whether they had ever played with Lego kits or see-saw (task two), whether they could swim and float, and whether they had ridden a boat (task three). The level of students' science knowledge seemed to correspond to their personal experiences and prior knowledge. Although they talked about having experiences related to the three science tasks, their conversations did not reveal personal experiences at home using science materials. They made little mention of the involvement of family members in science activities, nor did they talk about after school science activities.

Strategy use. Of the three groups, these students demonstrated the most frequent use of cognitive strategies. They often used strategies of relating personal experience or prior knowledge to the science tasks and using daily examples or events. They also used strategies related to peer collaboration, for instance, "She had her way of doing and I had mine. And when we put both our ways together, it made a better way than if one person had done it," and, "Both of us did it together and both of us learned things that we didn't know before. Maybe she learned something that I knew, or maybe I learned something that she knew before and she taught me."

At the completion of each science task, the teachers asked students, "Tell me about any specific techniques or methods that helped you do well today" (or rephrased variations). These students indicated moderate strategy use in their self-reports, which was somewhat inconsistent with the frequent use of cognitive strategies observed as they performed the tasks. The strategies that they reported were more global and reflected notions of effort or hard work (e.g., "because I did my best" or "with will"), rather than behavior specifically related to the science tasks.

Bilingual Haitian Creole-Speaking Group

Language. These students typically produced short written language samples and brief oral communication. Following teacher initiation and requests, these students typically spoke in brief turns of single sentences or short phrases. They often spoke in unison or repeated each other's responses. The tempo of discourse and interactions was slow and deliberate, as the students intently observed the teacher and each other and used long wait times between turns.They displayed restrained behavior and rarely initiated interactions with the teacher, which seemed to indicate their respect for the teacher, rather than a lack of interest. Interest was high, in fact, as they expressed how much they enjoyed the science tasks.

These students used extensive gestures to supplement and enhance verbal communication. For example, they used index fingers to express the concept of "swirl," which was similar to what was observed with bilingual Spanish speaking students described earlier. Sometimes gestures replaced verbal expressions. For instance, they used their open hands going up and down to illustrate the movement of the lever, or two hands with the right one up and the left one down and vice versa to represent see-saw movement.

Science knowledge. Of the three groups, these students' science knowledge and vocabulary seemed to be the least developed. Their responses usually involved observations and descriptions. They had difficulty making explanations. Even when these students gave adequate responses, the responses tended to be brief and short. In the following example, using the task cards, one boy described and explained the lever concept:

> A man travels along. He sees the big rock, a little rock, and a stick had fallen on the road. He looks at it to see if he could figure where to move the big rock. So he gets out of the car and puts the little rock under the piece of wood close to the big rock. He pushes close to the other end down and moves the rock upward and back around.

While performing science tasks, the students were not explicit in relating their personal experiences or prior knowledge to the science tasks. They often lacked experiences or knowledge relevant to the tasks. For instance, some were not familiar with the satellite photos of a hurricane and a tornado, had not played with Lego kits, did not know how to swim or float, had not ridden a boat, nor had ever been to the ocean and were afraid of water. Not coincidentally, these students expressed great appreciation for the opportunities to engage in the science activities and asked to take the materials home to show their families.

Strategy use. While performing science tasks, these students displayed few of the cognitive strategies discussed in the literature or observed with the other students in this study. Instead, their performance usually occurred after observations of teacher demonstrations or each other's performance. They used observation, imitation, and attention to non-verbal cues. These appeared to be precursors to strategy development, or more incipient approaches for promoting learning.

In self-reports of strategy use at the completion of each science task, these students indicated little use of strategies. Some did not appear to understand the concept of strategy use. Instead, when asked about their use of strategies or special techniques, they simply said, "nothing," "no," and "a little imagination."

Monolingual English-Speaking Group

Language. In expressing ideas in oral and written communication, the length of written products and the mean length of speaking turns of this group fell midway among the three groups. These students engaged in the conversation in a linear sequence of turn-taking. The students and the teacher spoke individually, one at a time, usually in one to three complete sentences per turn. The pace of discourse was brisk, and conversations proceeded with little repetition.

Verbal communication dominated the interactions with little body movement, gesture, or facial expression. The students usually kept their arms under or quietly on the table, occasionally using gestures to enhance verbal expression. For instance, while describing and explaining the lever concept, students used their fingers to point out the relative distance of the lever arm from the fulcrum. They used hand gestures to supplement, but not to replace, verbal expression.

For instance, in describing the movement of a tornado, some students used a variety of hand motions that indicated swirling, while saying the word “swirl” or “spin” simultaneously.

Science knowledge. These students often demonstrated comprehensive science knowledge and adequate science vocabulary. They also demonstrated a range of science process skills, including observation, description, measurement, experimentation, explanation, prediction, causal interpretation, and generalization. In the following example, two boys provided a reasonable explanation of the concept of lever using science vocabulary succinctly:

> Jim: A person is driving down the road. And he sees this big rock, this little rock, and a board.
> Ken: Then he gets out of his car and starts looking around.
> Tim: So he makes a lever, puts a fulcrum and the load.
> Ken: Put the fulcrum closer to the load and farther from your force.
> Jim: And then he moves it and drives away.

In displaying science knowledge, these students revealed a key reason, i.e., personal experiences and prior knowledge related to the science tasks. Not only did they have a variety of experiences, they talked about science-rich home environments, such as, “My mom bought me a chemistry set. It’s huge,” and “I enjoy watching weather reports on TV.”

Strategy use. While performing science tasks, these students used cognitive strategies with moderate frequencies. Like bilingual Spanish speaking students, they used the strategies of relating personal experience or prior knowledge to the science tasks and using daily examples or events. Unlike the other two groups, these students demonstrated metaknowledge of science, for example, “It [the tornado in the bottle] is supposed to be a model of a real tornado,” or “You have to be very careful when you work with science equipment.”

Self-reports of strategy use indicated that all of these students understood the concept of strategy use and indicated frequent use of strategies. These strategies were specific to task performance, reflecting notions of prior knowledge and personal experiences related to the tasks (e.g., “Mostly remember what we did in science class”), or an awareness of the process of thinking (e.g., “listening to directions” and “common sense”). They also reported frequent use of science resources and activities at home and in school, for instance, “We did a science project about the hurricane in class, and we wrote a research paper on it,” and “My mom is a science teacher. When I go to her school, she always lets me fool around with the microscope. She brings me like dead animals and slides and stuff, and it’s cool.”

Discussion and Implications

The results indicated unique patterns of language, science knowledge, and cognitive strategy use within each language group, as well as distinct differences among the three groups. Bilingual Spanish speaking students engaged in lengthy and extensive oral and written communication, whereas bilingual Haitian Creole speaking students engaged in short and brief communication. Monolingual English students engaged in oral and written communication that fell midway among the three groups. These students gave responses in succinct statements and showed moderate use of higher level cognitive strategies, while demonstrating comprehensive science knowledge and adequate science vocabulary. In interpreting the similarities and differences among the three groups, it should be emphasized that there were variations among the dyads within each group.

The value of the results reside in understanding the patterns of interplay across the three language groups. Inverted U-relationships were observed among language, science knowledge, and cognitive strategy use. Students with little science knowledge and vocabulary produced the least amount of language, were unaware of the concept of strategy use, and rarely used cognitive strategies. Students with moderate science knowledge and vocabulary produced the largest amount of language, often talking in a circular and repetitive fashion, and frequently used a range of general strategies. Students with the most comprehensive science knowledge and mastery of science vocabulary used a moderate amount of language and a moderate number of strategies. They spoke precisely using strategies specific to science tasks.

In interpreting these results, it is important to consider that students developing proficiency in English may be praised as their language becomes lengthier, more elaborate, and complex. Moving from limited exchanges of a few words and phrases to more extensive speech of sentences and paragraphs is an important step in acquiring language proficiency (Fradd and Larrinaga McGee, 1994). However, the value of elaborated speech appears to be a critical but transitory point in the process of gaining full proficiency in English. In order to function successfully in science, students must refine their communication skills and express their ideas in precise statements. In addition, for students who lack science knowledge and vocabulary, learning how to use cognitive strategies could enhance science performance (Chamot and O'Malley, 1994). As students develop adequate science knowledge and vocabulary, conscious application or excessive use of strategies seem to begin to interfere with performance. Selective use of strategies specific to the tasks might be more beneficial and effective than applications of general strategies. The curvilinear relationships among language production, science knowledge, and cognitive strategy use deserve further investigation.

While the findings provide valuable insights for understanding the interplay among language production, science knowledge, and strategy use, the limitations of the study should also be considered. The study described how students performed, but did not attempt to modify or enhance students' performance. In a theoretical sense, the findings do not provide an explanation of how the relationships occur or which factors are most important for each group. In a methodological sense, the small number of students in each language group and the single geographic location in which the study was conducted limit generalizability. In addition, although the design of the study was intended to encourage congruent interactions and maximize students' performance, such opportunities do not typically exist in classrooms with large, diverse groups of students.

The results of the study have implications for enabling students to develop English proficiency and science performance. The curvilinear relationship of language production, science knowledge, and strategy use suggest a progression of language development and science learning within each language group and among the three groups. These results provide insights into the process of learning English as a new language and academic content of science simultaneously. Assessment and instructional activities can be developed to meet the common learning needs of each language group as well as unique needs of individual students. Establishing a knowledge base for effective science instruction that considers the needs and background knowledge of diverse groups of students and teachers is essential to make science learning a reality for all students.

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